JONES DAY

51 LOUISIANA AVENUE, N.W. • WASHINGTON, D.C. 20001.2113

TELEPHONE: +1.202.879.3939 • FACSIMILE: +1.202.626.1700

DIRECT NUMBER: (202) 879-3630
BOLCOTT@JONESDAY.COM

March 31, 2017

VIA ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington D.C. 20554

Re: Oral *Ex Parte* Notice
GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95;
RM-11664 and 11773; and WT Docket No. 10-112

Dear Ms. Dortch:

On March 29, 2017, representatives of The Boeing Company ("Boeing") met with staff of the Federal Communications Commission ("Commission") to discuss the above-referenced proceedings and Boeing's further technical analysis regarding spectrum sharing between the Upper Microwave Flexible Use Service ("UMFUS") and next-generation broadband satellite communications systems in the V-band. A list of meeting attendees is provided as Attachment 1 to this letter.

During the meeting, Boeing detailed its analysis and simulations of multipath transmissions from Boeing satellites into UMFUS receivers in the 37.5-40.0 GHz band potentially caused by reflections of satellite signals off of buildings, mountains, or other objects. The analysis and simulations demonstrate that any increase in interference to UMFUS receivers caused by multipath transmissions is almost entirely offset by reductions in interference caused by the blockage of satellite signals by many of these same objects. The discussion tracked closely with the technical presentation provided herein as Attachment 2 to this letter.

Boeing also identified during the meeting the assumptions that it used in its analysis and simulations of multipath conditions. The assumptions that were discussed during the meeting are identified in the presentation slide that is provided herein as Attachment 3 to this letter. Although this slide was not presented or distributed during the meeting, it is being provided with this letter for inclusion as a part of the record for this proceeding.

In addition, Boeing presented two video files during the meeting showing simulations that Boeing conducted of the multipath environment, one of them in a dense urban environment, such as New York City, and the second in a less dense urban environment, such as Miami. These video files are in .pdf format and have been separately uploaded to this ECFS submission.

Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

Bruce A. Olcott
Counsel to The Boeing Company

Attachments

ATTACHMENT 1
March 29, 2017 Ex Parte Meeting Attendees

Wireless Telecommunications Bureau

- John Schauble
- Catherine Schroeder (by phone)
- Blaise Scinto
- Charles Oliver
- Jeffrey Tignor
- Matthew Pearl
- Nancy Zaczek (by phone)
- Simon Banyai
- Janet Young

Office of Engineering and Technology

- Michael Ha
- Bahman Badipour
- Barbara Pavon
- Nicholas Oros
- Antonio Lavarello

International Bureau

- Jose Albuquerque
- Diane Garfield (by phone)
- Chip Fleming
- Kal Krautkramer (by phone)
- Jennifer Gilsenan
- Michael Mullinix

Boeing Participants

- Bruce Chesley
- Robert Vaughan
- Matthew Dzugan
- Audrey Allison
- Kim Kolb (by phone)
- Bruce Olcott

ATTACHMENT 2
Meeting Presentation

Spectrum Frontiers
V-band Spectrum Sharing Discussion

29 March 2017

TOPICS

- **Spectrum Frontiers Order and Topics for Reconsideration**
- **Boeing NGSO System Downlink PFD Operations**
- **Multipath Environment and Satellite DL interference into UMFUS**
  - **Satellite Multipath Environment Descriptions**
  - **Analysis Excursions – Satellite DL interference with Blockage and Reflections**
    - Urban canyon environment
    - Suburban/rural environments
  - **Summary of results and implications for ePFD approach**

Spectrum Frontiers Order and Reconsideration

- **Spectrum Frontiers Order acknowledged the need for spectrum sharing between UMFUS and broadband satellites, but needed to go further**
- **Key aspects of the Order which deserve reconsideration:**
  - Beamforming capabilities of UMFUS devices
  - Power control application in UMFUS deployments
  - UMFUS Base Station maximum EIRP
  - Part 101 Fixed and new UMFUS Part 30 “merged” regulations (omni-directional antennas and 85 dBmi transmission level)
  - Shared FSS operations in the 42.0-42.5 GHz band
  - Restrictions on earth station siting (quantity per PEA, population percentage limits)

Beamforming and Power Control for UMFUS Devices

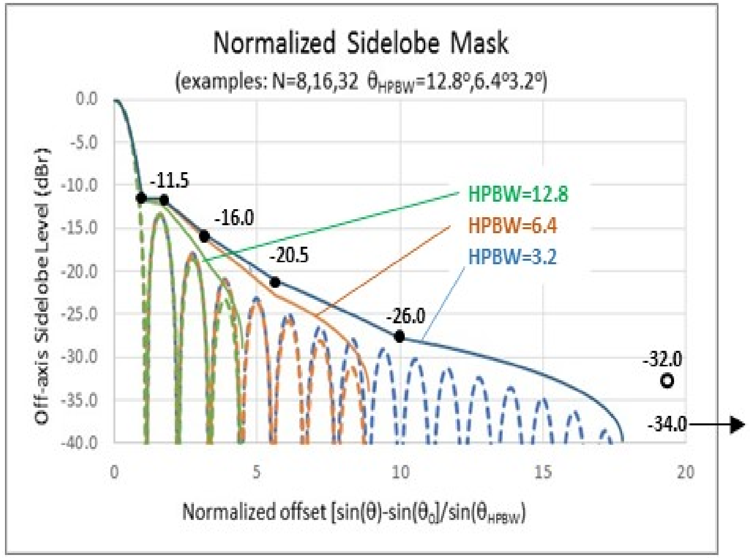
For an array with half-power beamwidth θ_{HP} at broadside, at an angle if incidence θ, given an array steering angle θ_0 both measured from array broadside, define: $u = \sin(\theta)$ and $u_0 = \sin(\theta_0)$ $u_{HP} = \sin(\theta_{HP})$ $\Delta u = (u - u_0)$

$$\gamma = \left|\left(\frac{\Delta u}{u_{HP}}\right)\right| \quad and \quad \gamma_{limit} = \left(\frac{1}{u_{HP}}\right) \qquad with \quad G_E(\theta) = -12(\theta/\theta_E)^2 \quad and \quad \theta_E = 90^o$$

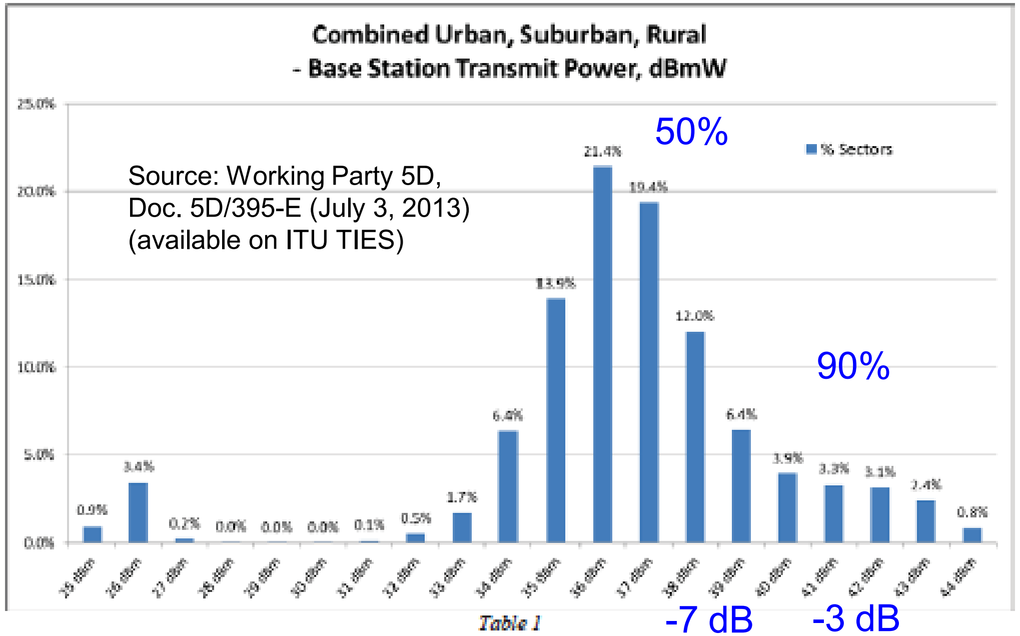
$$for\ \gamma_{min}(k) < \gamma \le \gamma_{max}(k) \ \ and\ \gamma, \gamma_{max}(k) < \gamma_{limit}$$

$$G_{max}(\gamma) = G_E(\theta) + SLL_{dBr}(k) - \delta * (\gamma - \gamma_{min}(k))$$

Normalized γ_{min}	Normalized γ_{max}	Sidelobe level SLL_{dBr}	Slope δ
1.00	1.675	-11.5	0
1.675	3.375	-11.5	2.65
3.375	5.625	-16.0	2.00
5.625	10	-20.5	1.257
10	19	-26.0	0.667
19	37	-32.0	0.111
37	Inf	-34.0	0



- **Importance of beamforming acknowledged by many UMFUS proponents**
- **Expected use of beamforming was heavily relied on throughout the Order**
  - Off-axis rules already exist for other services, including LMDS and 39 GHz fixed service
- **Should adopted a simple off-axis gain mask based on planned UMFUS small planar array devices**
  - Would not impede the development or flexibility of UMFUS technology



- **Power control widely used in mobile services to maximize network capacity and conserve batteries**
- **Power control needed for intra-service sharing**
- **Relied on in analyses of sharing with FSS and FS**
  - Advantages range from 3 to 7 dB, 50% to 90% of the time
  - Base station power control range will be even broader
- **Adopt simple rule language requiring power control mechanisms (similar to other wireless services)**

Spectrum Frontiers – Other Topics for Reconsideration

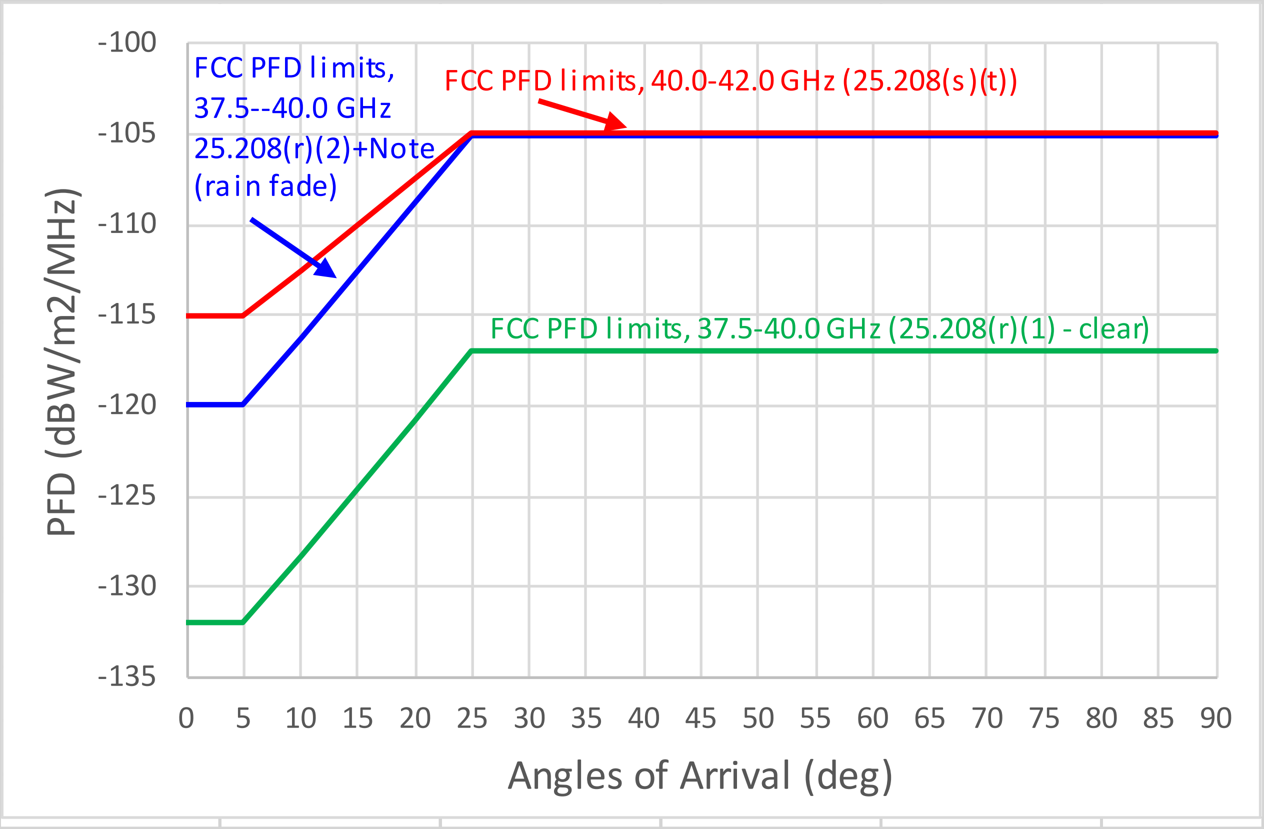
Topic	Rationale

Base Station Maximum EIRP	• 75 dBm/100 MHz power adopted based on claims of wide area networks and indoor penetration
	  • mmW spectrum optimal for small cells and is not practical for wide area networks
	  • Higher power will not facilitate indoor penetration, it will only increase multipath interference
	• Should reduce UMFUS base station maximum EIRP to 65 dBm/100 MHz to promote sharing

Part 101 FS and UMFUS merged regulations	• No one sought authority to operate omni-directional “broadcast” networks using UMFUS spectrum • UMFUS should not be permitted to use omni-directional antennas either for fixed or mobile services • Part 30 co-mingles rules for fixed “hubs” at up to 85 dBm and mobile “base stations” at 75 dBm • Fixed service rules should remain in Part 101, which is entitled “Fixed Microwave Services”
FSS in 42.0-42.5 GHz Band	• 42.0-42.5 GHz band is very appropriate for FSS since it is adjacent to the 40.0-42.0 GHz band • FSS can operate on a shared basis in this spectrum just as proposed for the 37.5-40.0 GHz band

Earth Station Siting Rules (PEAs/percent population)	• 0.1% limit makes it extremely difficult to locate earth stations in rural PEAs. Tiered approach better:
	  • Retain a strict percentage limit in populous PEAs (*i.e.*, 0.1 or 0.2 percent)
	  • Allow a higher, but still very low, percentage in very rural PEAs (i.e., 5 percent)
	• Compliance with percentage limits makes numerical limits irrelevant
	  • Numeric limit of 3 earth stations per PEA is too restrictive to accommodate Boeing’s earth station requirements and could not accommodate multiple V-band satellite systems

Boeing NGSO Downlink PFD Operation



NOTE TO PARAGRAPH (R): The conditions under which satellites may exceed these power flux-density limits for normal free space propagation described in paragraph (r)(1) to compensate for the effects of rain fading are under study and have therefore not yet been defined. Such conditions and the extent to which these limits can be exceeded will be the subject of a further rulemaking by the Commission on the satellite service rules.

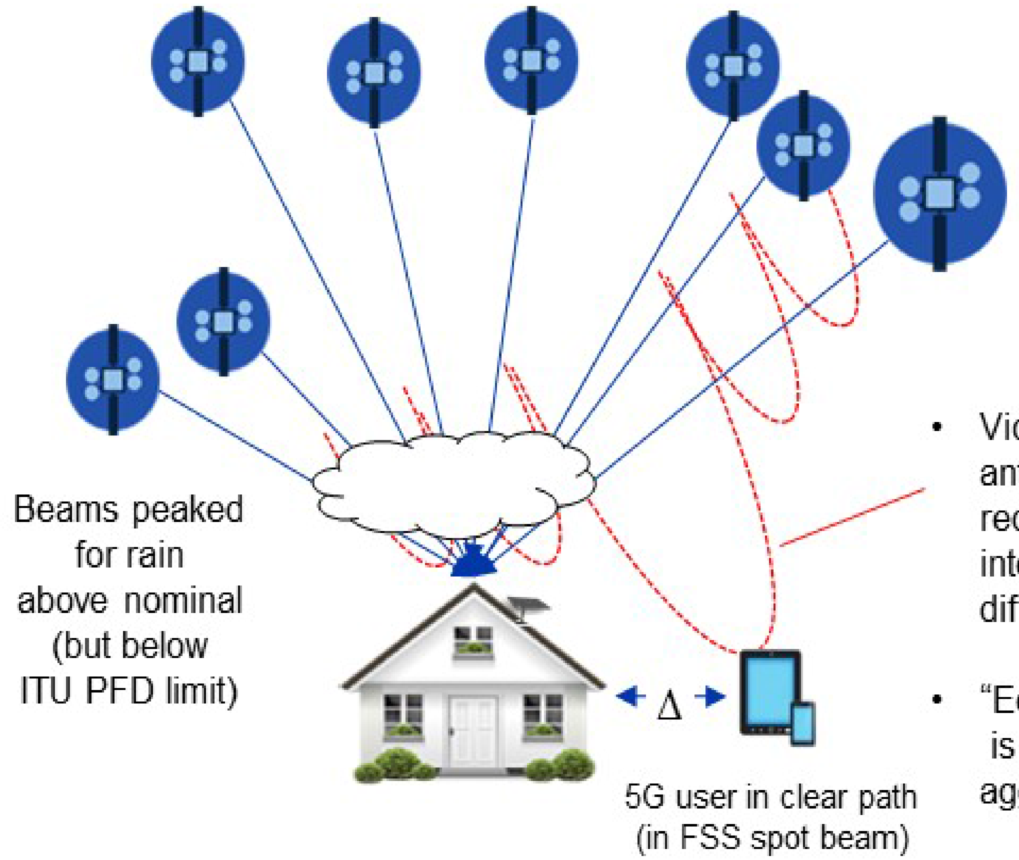
- Boeing V-band NGSO System operation is fully compliant with current FCC rules
- In the 40.0-42.0 GHz band, satellites operate up to -105 dBW/m2/MHz in any condition
- In the 37.5-40.0 GHz band, satellites operate below -117 dBW/m2/MHz in clear air conditions
  - Satellites will raise their EIRP and EIRP density <u>in rain fade only</u> and operate below the -105 dBW/m2/MHz maximum limit
- Operations during rain fade are subject to a Note which indicates further study and rulemaking needed
  - The Commission should resolve these issues in the Spectrum Frontiers proceeding
  - Both the NPRM and FNPRM sought comment on these issues, making them ripe for resolution

Spectrum Frontiers FNPRM

Multipath Environment and Impacts on Satellite DL Interference

29 March 2017

Equivalent PFD ("ePFD") Analyses are Appropriate for Calculating FSS to UMFUS Interference



- Victim 5G receiver antenna pattern reduces total interference from different satellite paths
- "Equivalent PFD" is less than simple aggregate combined

$$ePFD = 10log_{10}\left(\sum_{k=1}^{Nsats} 10^{\frac{(G_r^k(\theta_k,\phi_k)+PFD_k)}{10}}\right) - (G_{r-pk})$$

N_{sats} = Number of total NGSO satellites radiating beams at the particular ground point
PFD_k = incident PFD of the k[th] NGSO satellite at the ground point in dBW/m2/MHz
$G_r^k(\theta_k, \phi_k)$ = Gain of the 5G victim receiver antenna in the direction toward the kth NGSO satellite, in dBi
G_{r-pk} = Peak gain of the 5G victim receiver (usually G_r (0,0) at boresight), in dBi

$$INR_{dB} = [ePFD + G_{r\text{-}pk} - 10\log_{10}(4\pi/\lambda^2) - k - T_r]$$

$$(I/N)_{deg} = 10\log_{10}(10^{(INR/10)}+1)$$

λ = wavelength in m; λ ~= $(0.3/F_c)$ where F_c is in GHz

G_r = Isotropic gain of the 5G receiver in the direction of the arriving PFD signal, in dBi

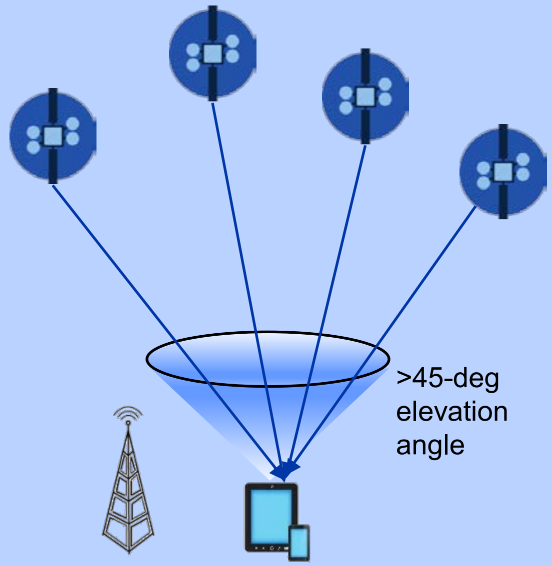
K = Boltzmann's constant, -228.6 dB W/K-Hz

T_r = 5G receiver noise temperature in dB/K, calculated as $10\log_{10}(T_b+290*[10^{(NF/10)}-1])$ where T_b= background temperature (usually 290K for terrestrial background and/or rain) and NF = noise figure of the 5G receiver in dB

- **ePFD methodology used for satellite spectrum sharing correctly models FSS/UMFUS sharing**
- **Worst-case conditions – <u>satellite power raised</u> for rain fade with <u>clear sky path</u> to UMFUS receivers**

Outdoor Multipath Signal Environment Description

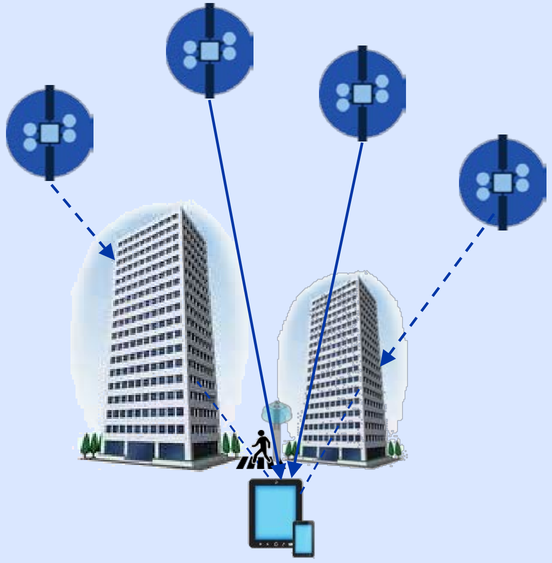
LOS signals



- Direct LOS path
- Only free space path loss assumed
- Increased satellite power for rain fade applied
- Highest received PFD from satellite
- Rx antenna gain reduces total interference (ePFD)

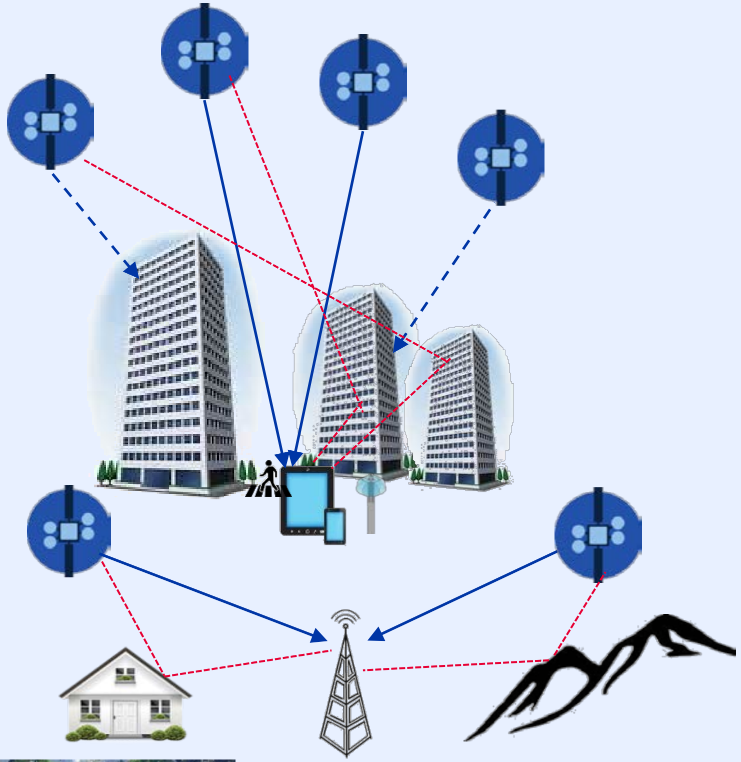
✓ Existing Regulations - precedent

Blockage/ Shadowing



- Obstructs/obscures direct LOS
- “Removes” LOS signals and their associated received PFD
- Reduces total interference prior to 5G receiver
- Rx antenna gain reduces total interference

Reflection



- “Adds” copies of satellite signals at lower PFD values and widely varying angles (delays/phases)
- Rx antenna gain reduces total interference

ePFD methodology provides accurate model of NGSO interference with clear regulatory approach

Impacts of clutter/obstructions in various environments investigated to show robustness of clear LOS ePFD

Basic Reflection and Surface Materials Properties

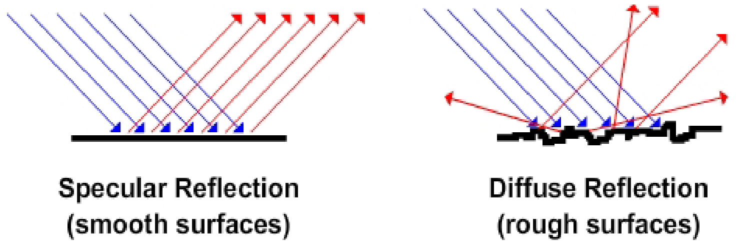
- **Reflections can be specular or diffuse based on the surface properties**
- **Classic specular reflection is rarely experienced especially at higher mmW frequencies**
  - Most surfaces are rough (at mmW frequencies), coated,or consist of multiple mixed materials (e.g. concrete/glass)
- **ITU-R P.2040 contains recommendations for relative permittivity and reflectivity calculations for materials**
- **True scattering/multipath environment modeling requires a highly complex physical environment model**
- **Most reflected signals are -7 to -13 dB attenuated vs the direct LOS signal**
- **Basic specular reflectivity models have been added to satellite interference scenarios to illustrate the effects vs clear LOS model**

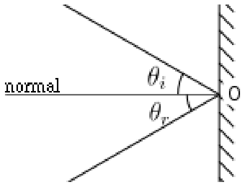
Table 3 Material Properties

(per ITU-R P.2040-1) $\varepsilon_r = a f^b$

Material class	Real part of relative permittivity	
	a	*b*
Vacuum (≈ air)	1	0
Concrete	5.31	0
Brick	3.75	0
Plasterboard	2.94	0
Wood	1.99	0
Glass	6.27	0
Ceiling board	1.5	0
Chipboard	2.58	0
Floorboard	3.66	0
Metal	1	0
Very dry ground	3	0
Medium dry ground	15	−0.1
Wet ground	30	−0.4

Material	Average Reflectivty (dB), 45 to 75 deg incidence
Concrete	-6.72
Brick	-7.77
Plasterboard	-8.70
Wood	-10.84
Glass	-6.29
Ceiling board	-13.61
Chipboard	-9.30
Floorboard	-7.86
Metal	0.0
Very dry ground	-8.62
Medium dry ground	-6.89
Wet ground	-6.89



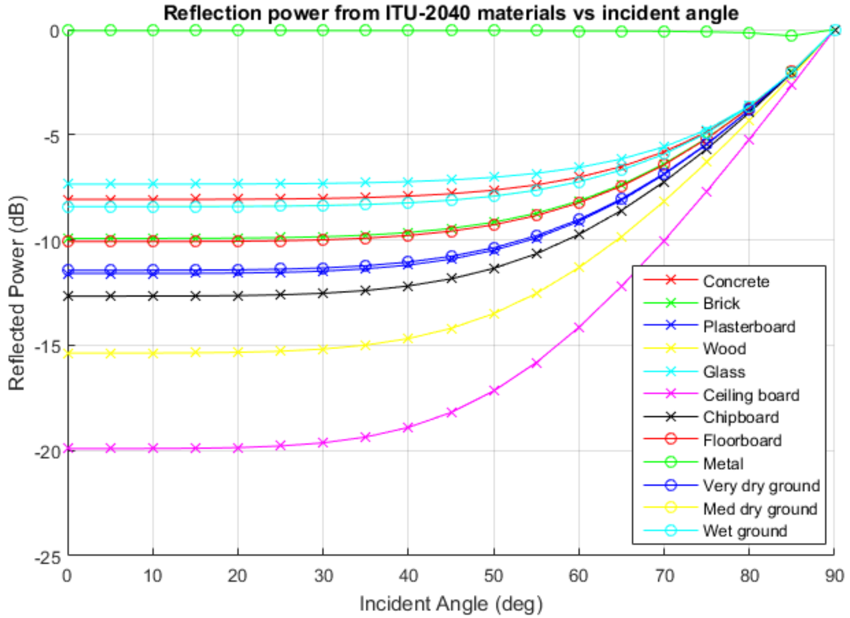


$$R_{eTE} = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}$$

$$R_{eTM} = \frac{\varepsilon_r \cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}$$

$\varepsilon_r = relative\ permittivity$

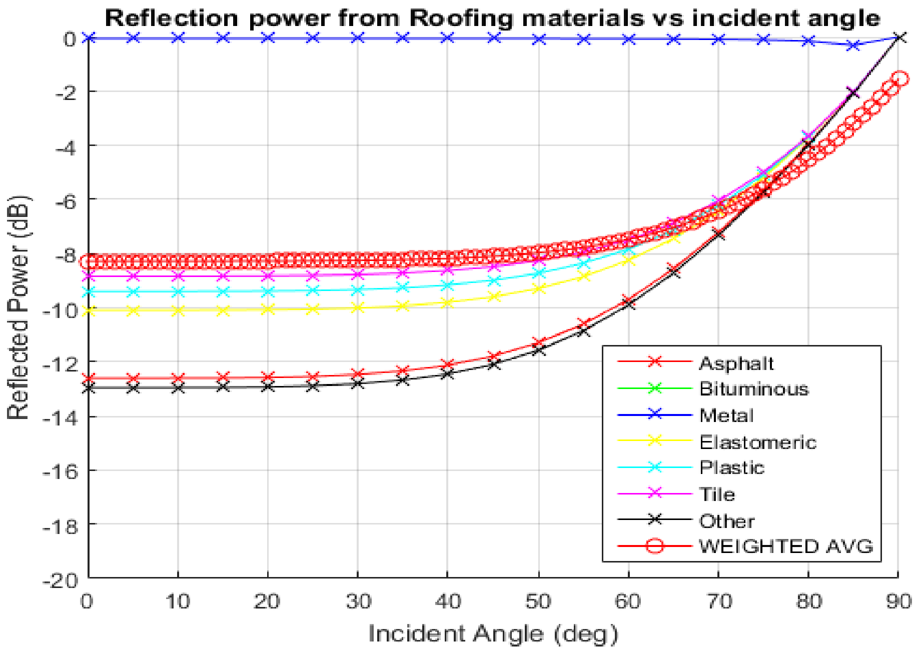
$Index\ of refraction\ n = \sqrt{\varepsilon_r \mu_r}$



Other Surface Materials Properties - Roofing

- **Types of roofing surface materials utilized in USA construction is based on data available at** https://www.bdcnetwork.com/us-roofing-demand-predicted-rise-driven-new-construction **(as cited by Straight Path in their FNPRM Reply Comments)**
- **Metal Roofing is < 10% of materials types. Metal roofs are often coated with paint or polymers and have mounting ridgelines that disrupt reflections**
- **Roofing Material permittivity and reflectivity are shown in the plots to the right**
  - Rooftop materials are distributed according to the percentages and assigned the reflectivity shown
  - Weighted average reflectivity curve is also shown given the expected percentage of materials
- **Office building wall materials are assumed to be concrete, brick and glass mixtures**
- **Suburban walls are mixtures of all types**
- **Ground types are mixed between concrete (streets) and medium dry or wet ground**

ANTICIPATED DEMAND FOR ROOFING MATERIALS (USA)	% Demand 2017	Relative Permittivity ε_R	Average Reflectivity (dB), 45- to 75 deg incidence
Asphalt Shingles	58.4%	2.6	-9.36
Bituminous Low-Slope Roofing	13.2%	2.5	-9.56
Metal Roofing	9.0%	1.0	0.00
Elastomeric Roofing	7.7%	3.65	-7.96
Plastic Roofing	5.1%	4.1	-7.56
Roofing Tile	5.0%	4.55	-7.24
Other	1.6%	2.5	-9.56



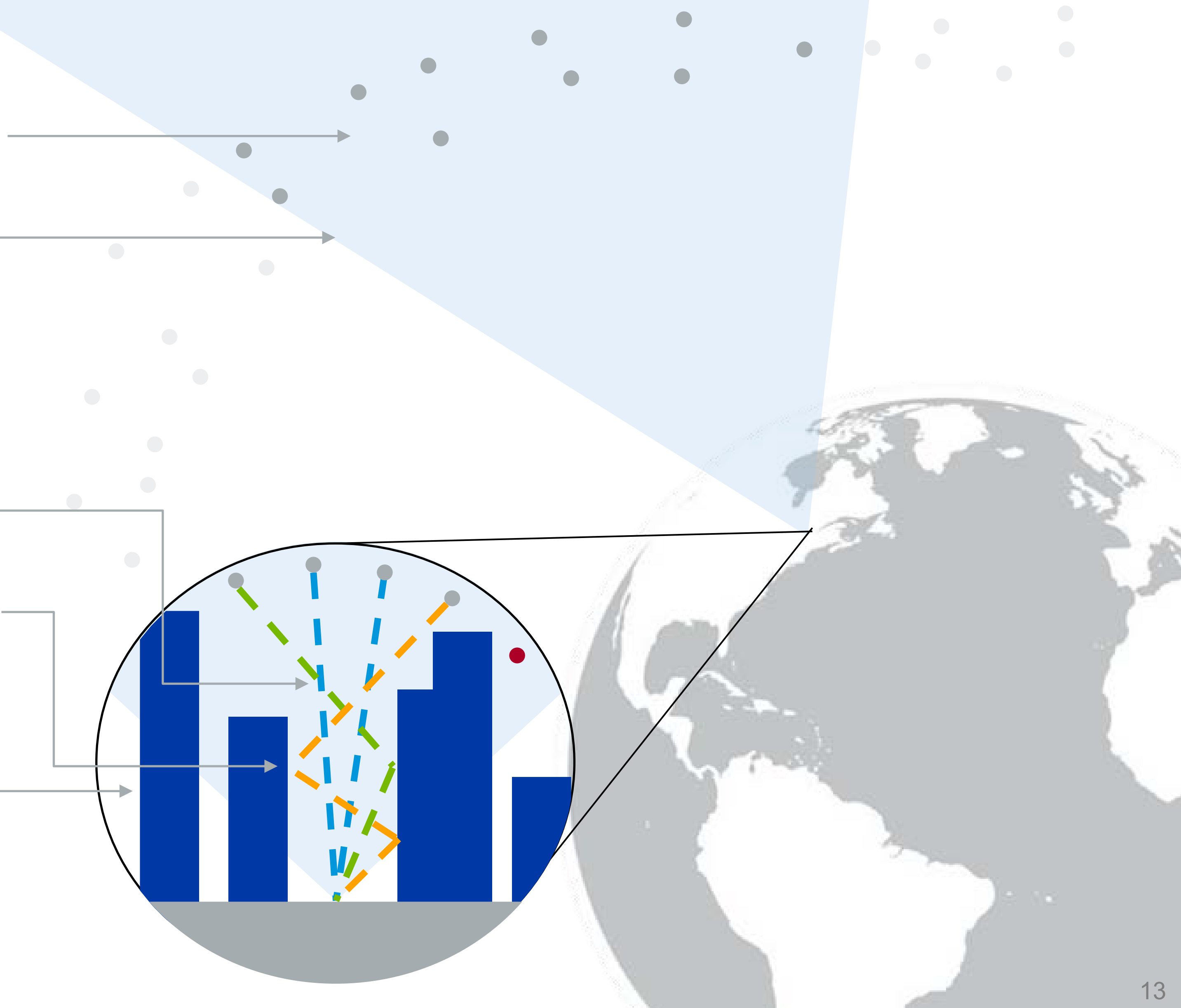
Satellite DL interference Modeling in Multipath Environment (Blockage and Reflections)

29 March 2017

Downlink Interference: Multipath Modeling Approach

Assumptions:

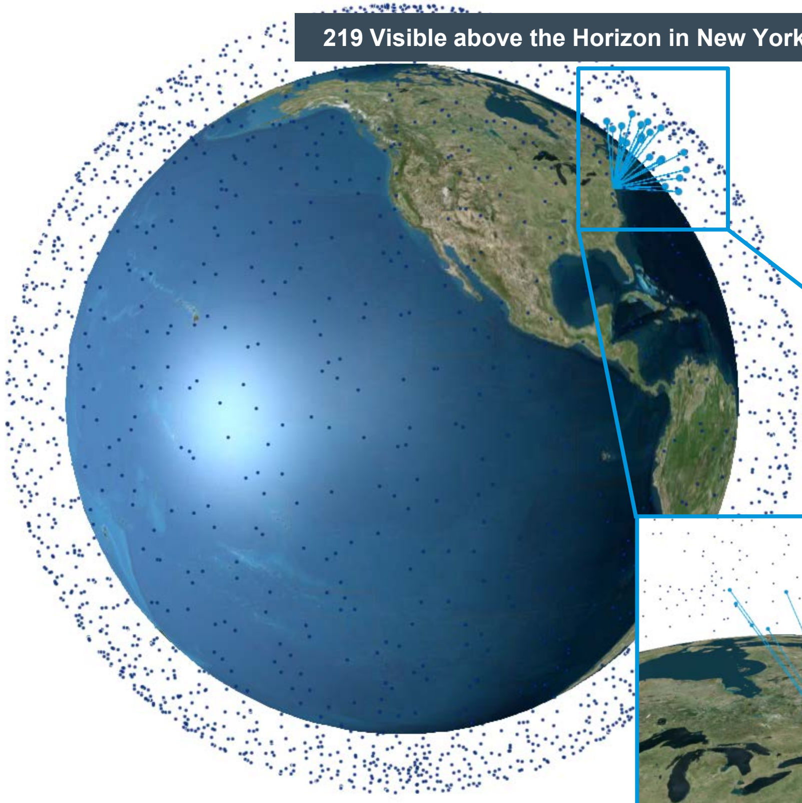
- **Boeing's constellation of 2956 LEO satellites is transmitting at 39 GHz**
- **All satellites at 50° elevation angle or higher are assumed to be radiating down to the site of interest**
- **Signal-Paths to the site-of-interest under consideration are of 3 main types:**
  - Direct Line of Sight
  - Single Reflection
  - Double Reflection
  - Signal-Paths of three or more reflections are not considered here. They are deemed unnecessary due to their extreme degradations, and thus overly complex for this model.
- **Each reflection induces losses to the reflected ray as a function of reflection-angle and reflecting-surface-material as described by the permittivity equations in ITU-2040**
- **3D-Building models are obtained via the open-street-map project at http://osmbuildings.org/**
- **Per-Satellite PFD levels are commensurate with In-Beam Rain-Fade conditions**

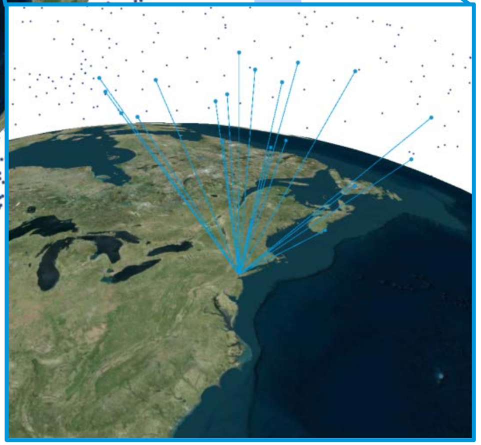


Link Degradations/ePFD with Multipath

NGSO constellation (2,956 satellites)

219 Visible above the Horizon in New York City

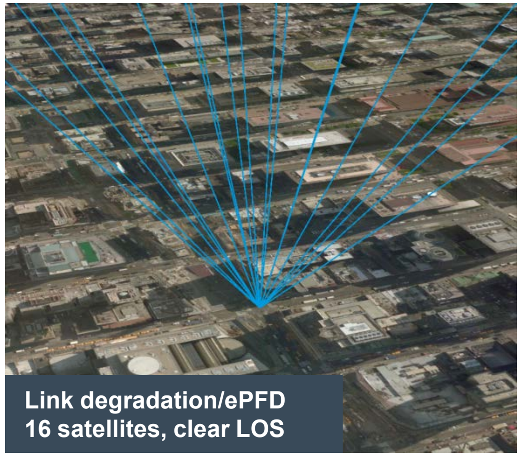




14 satellites operating over NYC

Victim Type = User Handset

Line of Sight Analysis (No Buildings)



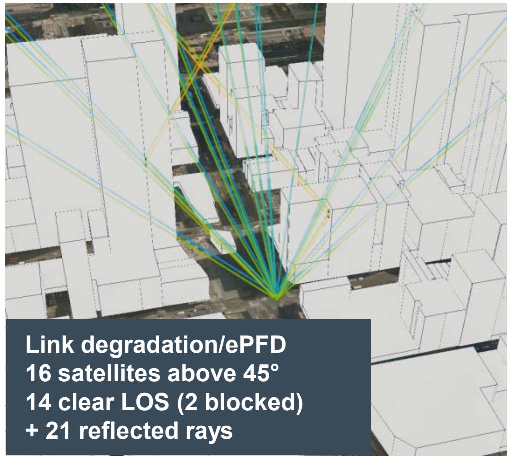
Link degradation/ePFD
16 satellites, clear LOS

Satellite ID	Ray Type	Reflection Losses	Isolation from Peak	Gain Adjusted PFD
0	LOS	0	-17.9021	-129.829
1	LOS	0	-16.8579	-128.902
2	LOS	0	-13.7979	-125.933
3	LOS	0	-0.84704	-113.014
4	LOS	0	-34.9674	-147.036
6	LOS	0	-29.9131	-141.746
7	LOS	0	-38.9764	-151.11
8	LOS	0	-0.35856	-112.51
9	LOS	0	-21.3755	-133.208
10	LOS	0	-28.5438	-140.322
11	LOS	0	-17.3513	-129.535
12	LOS	0	-16.5318	-128.723
13	LOS	0	-41.765	-153.592
14	LOS	0	-6.60778	-118.784

ePFD: -108.8 dBW/m²/MHz

I/N Degradation: 0.53 dB

Multipath Analysis (with Buildings)



Link degradation/ePFD
16 satellites above 45°
14 clear LOS (2 blocked)
+ 21 reflected rays

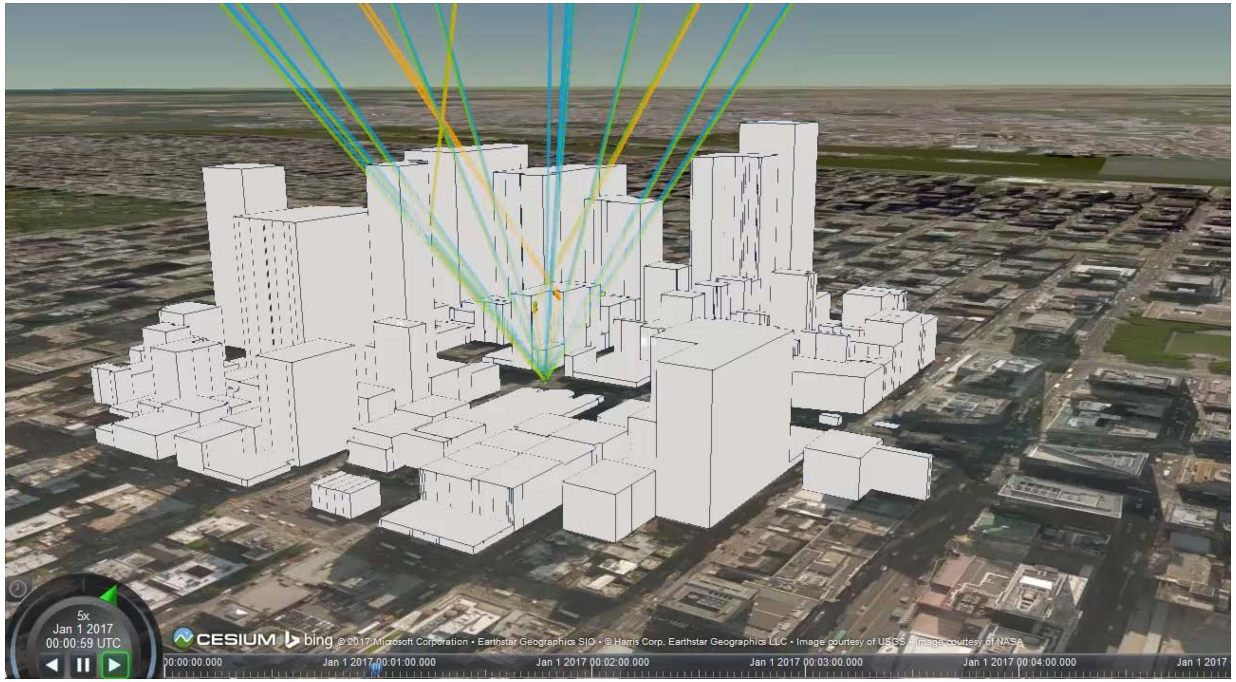
Satellite ID	Ray Type	Reflection Losses	Isolation from Peak	Gain Adjusted PFD
1	LOS	0	-16.4275	-128.471
1	1 Ref.	-8.32341	-40	-160.367
2	LOS	0	-12.9544	-125.089
2	1 Ref.	-8.35316	-40	-160.488
3	LOS	0	-0.78234	-112.949
3	1 Ref.	-8.06736	-40	-160.234
4	LOS	0	-31.506	-143.575
4	1 Ref.	-8.3318	-0.24346	-120.644
7	LOS	0	-27.847	-139.98
7	1 Ref.	-8.05722	-40	-160.191
8	LOS	0	-23.9648	-136.116
8	1 Ref.	-8.06249	-40	-160.214
9	LOS	0	-30.1021	-141.934
9	1 Ref.	-7.96109	-40	-159.793
10	LOS	0	-28.7359	-140.514
10	1 Ref.	-7.94158	-40	-159.72
11	LOS	0	-24.4516	-136.636
11	1 Ref.	-8.36979	-40	-160.554
12	LOS	0	-24.6974	-136.888
12	2 Ref.	-15.3706	-40	-160.561
13	LOS	0	-28.0227	-139.849
13	1 Ref.	-8.24331	-40	-160.07
14	LOS	0	-6.80974	-118.986
14	1 Ref.	-8.36751	-40	-160.544

ePFD: -111.1 dBW/m²/MHz

I/N Degradation: 0.32 dB

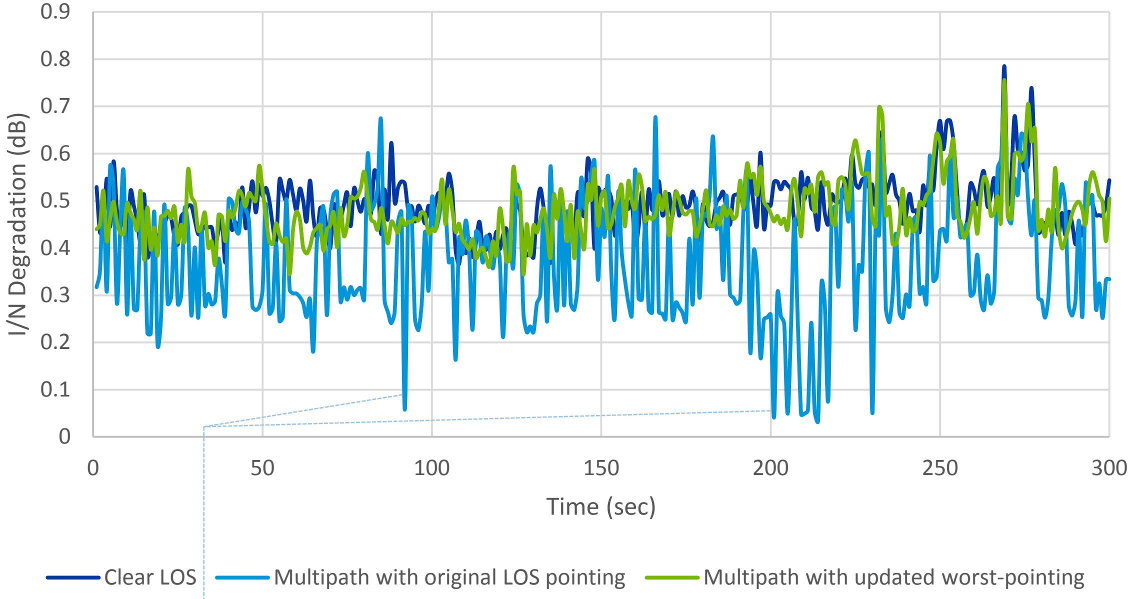
Downlink Interference Example: User Handset - Urban

New York



Line of Sight Ray
Single Reflection Ray
Double Reflection Ray

I/N degradation

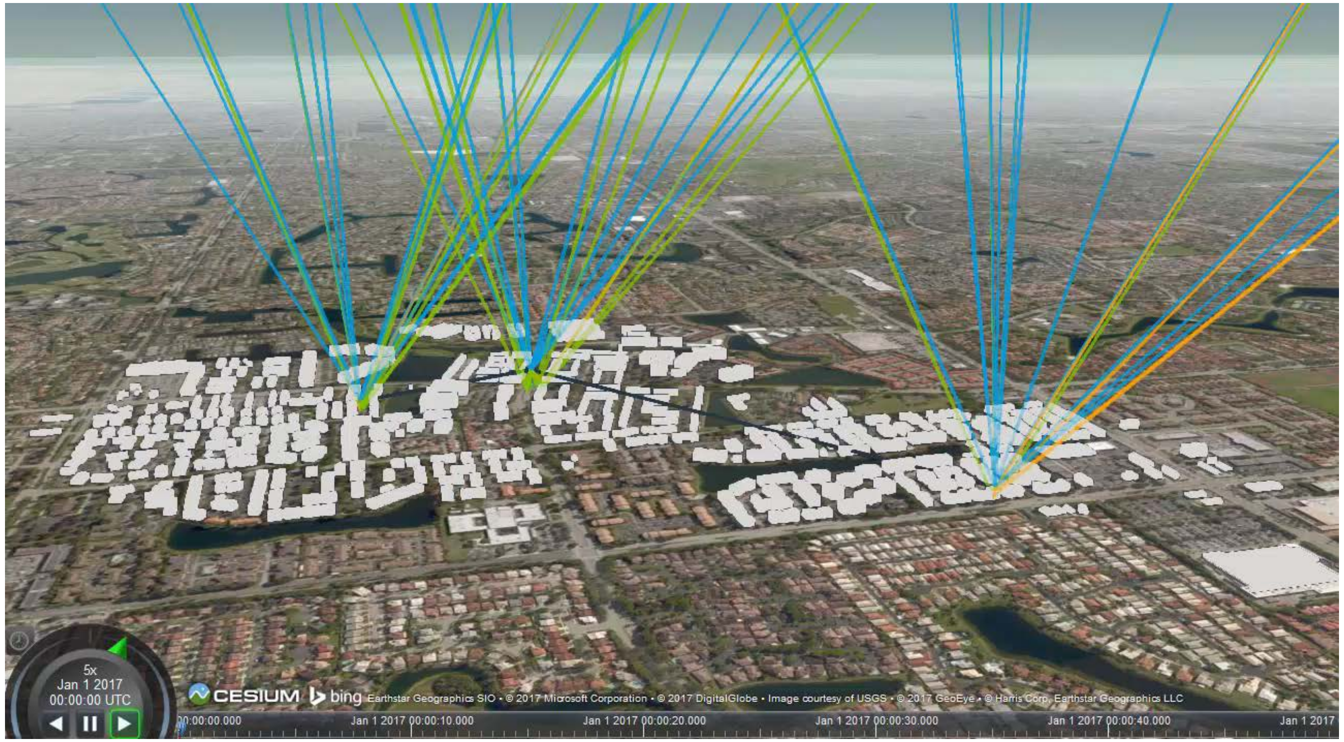


Large dips in Multipath ePFD occur when the satellite(s) at bore-sight during LOS simulations is blocked by a building for a few moments

- **While exact building geometry is important for instantaneous measurements, in general Urban Multipath is ePFD causes equal and often less link degradation than a pure LOS analysis**

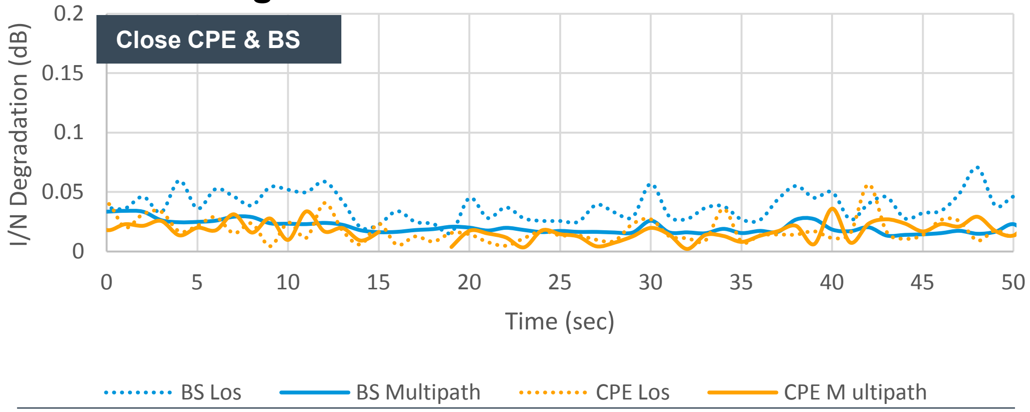
Downlink Interference Example: Suburban Case

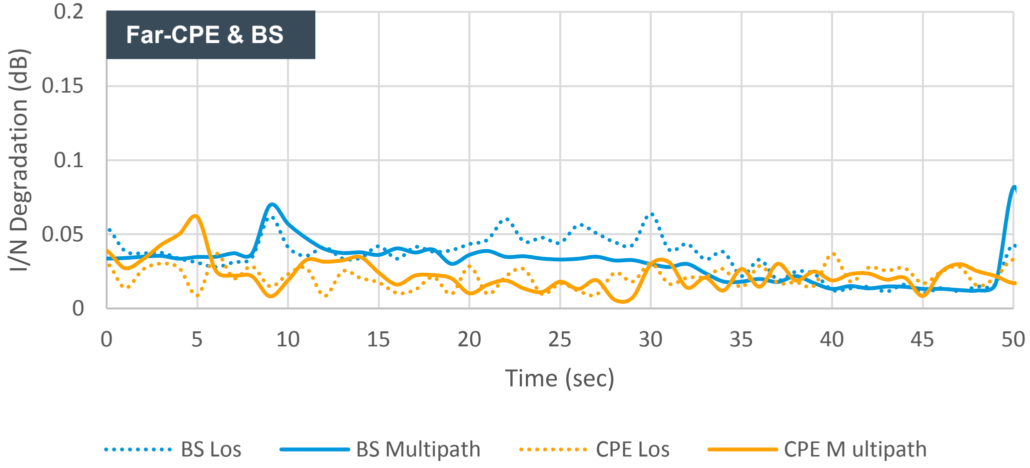
Suburban Miami



- Line of Sight Ray
- Single Reflection Ray
- Double Reflection Ray

Link degradation – CPEs & Base Stations

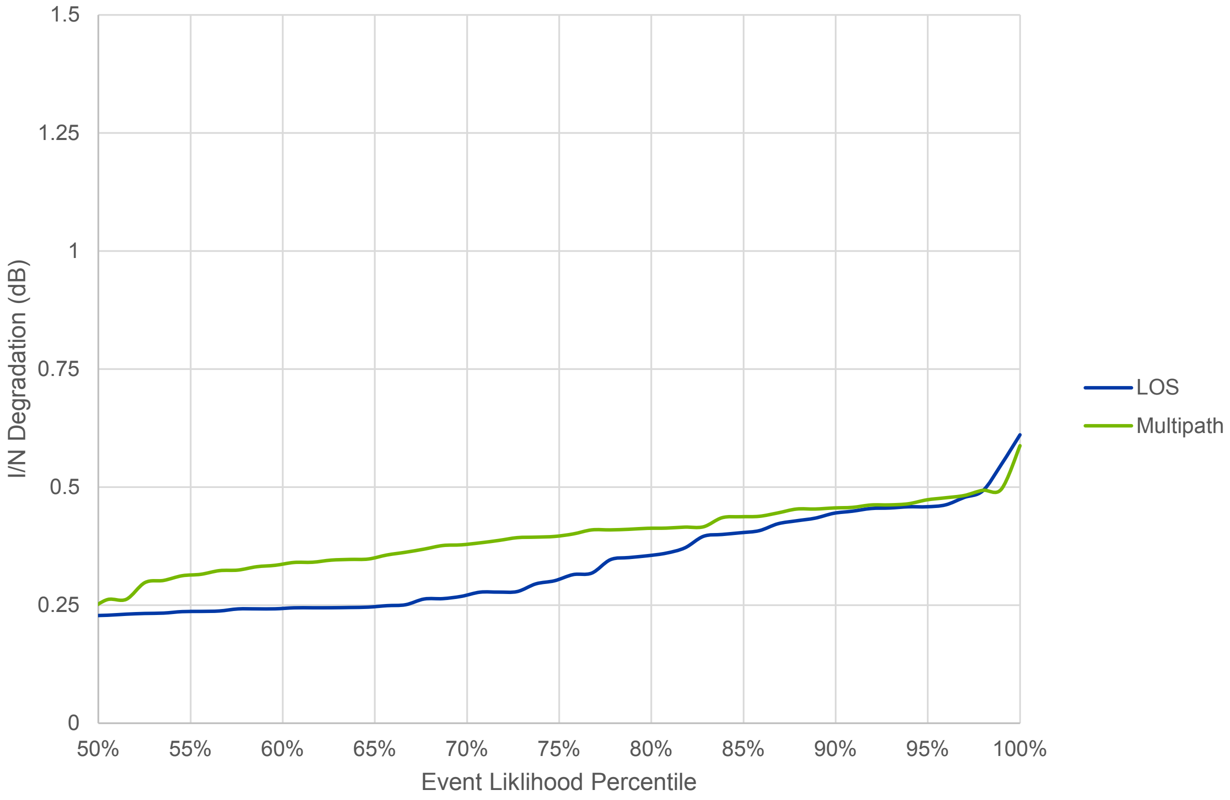




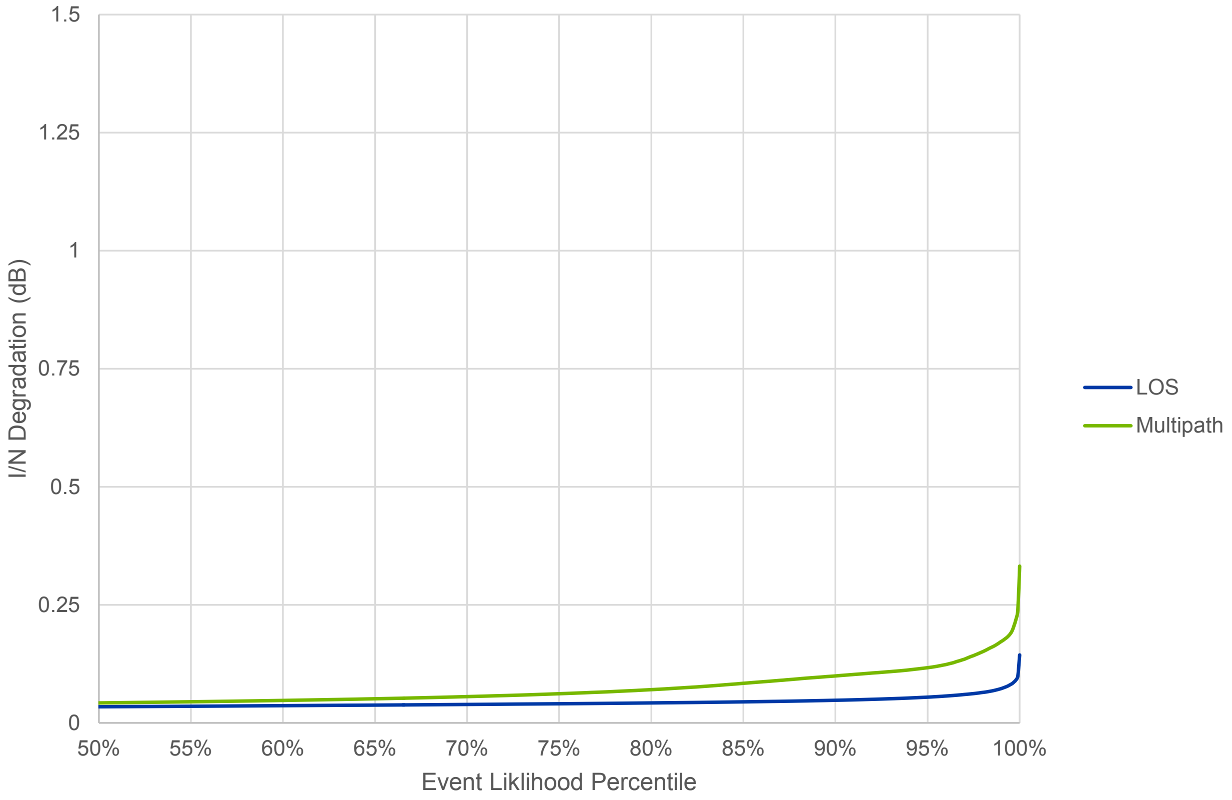
- **Introduction of Multipath environment does not affect the larger trend that degradation is at its worst when the antenna is pointed upwards (“Close” case for CPE, “Far” case for BS)**

Multipath Impact on Statistical ePFD: Urban Scenario

Handsets



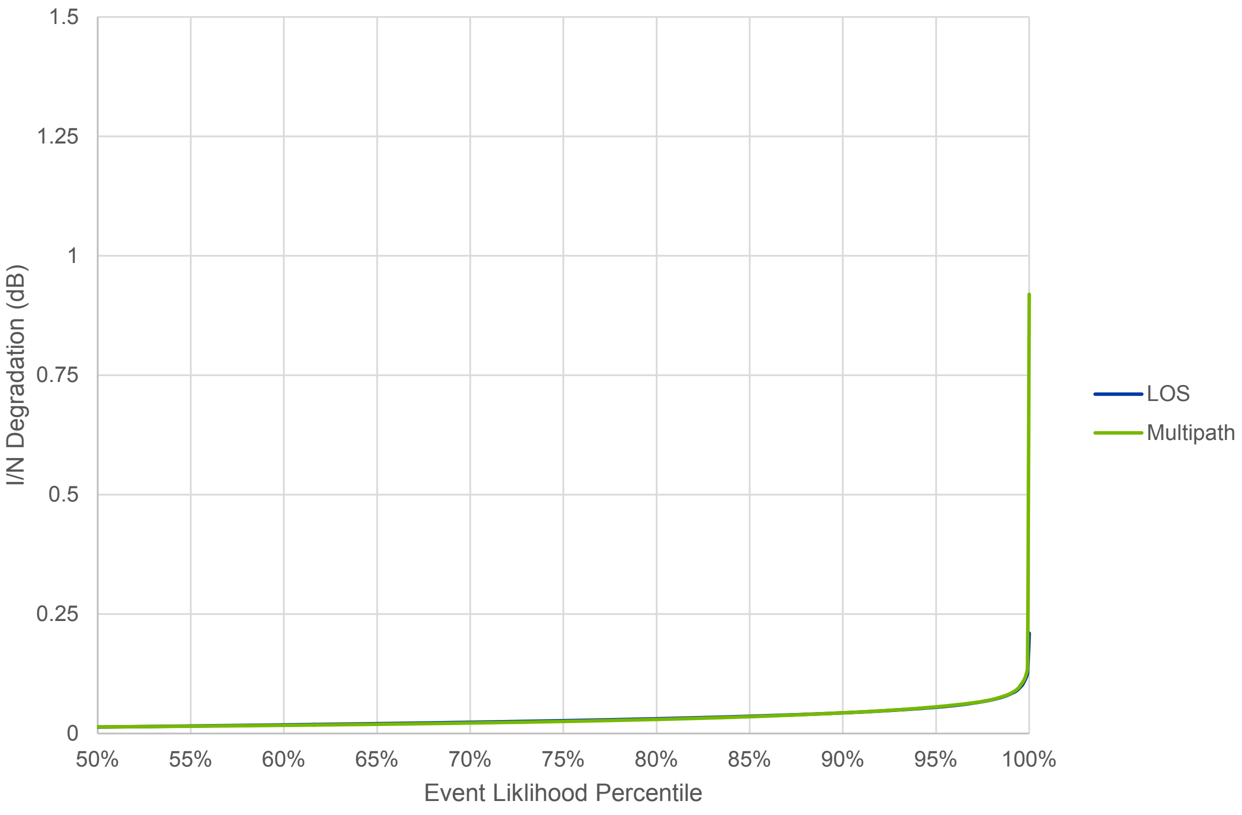
Base Stations



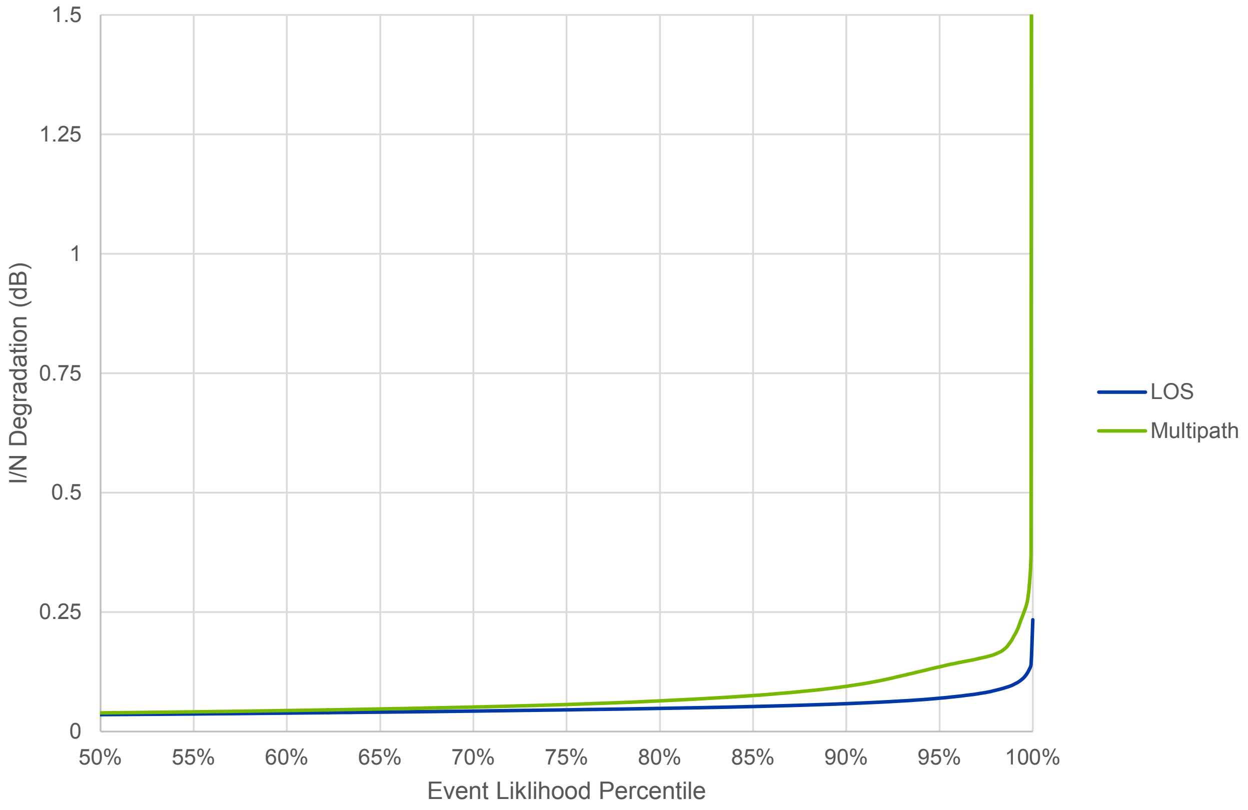
In Urban areas, Multipath slightly increases BS I/N , but reduces ePFD seen by users

Multipath Impact on Statistical ePFD: Suburban Scenario

CPE



Base Stations



In Suburban areas, Multipath has a slight impact on Base Stations while being neutral to CPEs

Summary - V-band DL Spectrum Sharing with NGSO FSS

- **Spectrum Frontiers order enables highly efficient UMFUS operations**
- **Several key topics which were raised by Boeing and other parties are not adequately addressed in the final Order and deserve reconsideration**
  - Beamforming and power control for UMFUS devices, Base Station maximum EIRP, Part 101 FS and new UMFUS Part 30 “merged” regulations, and details of restrictions on siting of earth stations
- **Boeing NGSO system PFD operations will comply with FCC regulations in clear air conditions and only raise PFD during rain fades**
  - Details of rain fade operations and existing Note can be replaced by appropriate ePFD regulations which limit potential FSS interference into UMFUS devices
- **Detailed multipath environments and reflections have been incorporated into FSS-UMFUS DL interference and ePFD model**
- **Results show that clear LOS ePFD and link degradations are highly representative and provide accurate, practical basis for interference regulations**

ATTACHMENT 3
Multipath Simulation Assumptions

UMFUS Equipment and Pointing Conditions for Multipath Cases

<table>
<tr><th>Scenario</th><th>Scenario Description and UMFUS equipment configuration
Base Station</th><th>Scenario Description and UMFUS equipment configuration
Mobile UE/Handset OR Transportable CPE</th></tr>
<tr><td>• Urban</td><td>• Urban Location – New York (Times Square)
• Base station location – Times Square
• Base station parameters
— Base Station height: 130m (building-side)
— Size: 32x32 1024-elements (Peak gain 33 dBi, NF = 5 dB)
— Single sector (120-deg)
— Sector boresight orientation: horizontal
— Electronic beam pointing; uniformly randomly electrically scanned within +/-60-deg off-boresight</td><td>• Urban Location – New York (Times Square)
• Handset location – Outdoor -Urban Macro
• Mobile UE parameters
— UE/handset height: 2m
— Size: 4x4 16-elements (Peak gain 16 dBi, NF = 7 dB)
— Pointing options
— Clear LOS: physical boresight pointed at satellite
— Multipath: physical boresight pointed at random LOS or reflection</td></tr>
<tr><td>• Suburban</td><td>• Suburban Location – Miami
• Base station parameters
— Base Station height: 29m
— Size; 32x32 1024-elements (Peak gain 33 dBi, NF = 5 dB)
— Single sector (120-deg)
— Sector boresight orientation: horizontal
— Electronic beam pointing; uniformly randomly electrically scanned within +/-60-deg off-boresight</td><td>• Suburban Location – Miami
• CPE parameters
— CPE height: 9m (rooftops)
— Size; 8x8 64-elements (Peak gain 21 dBi, NF = 6 dB)
— CPE planar array orientation: horizontal
— Electronic beam pointing; uniformly randomly electrically scanned within +/-60-deg off-boresight</td></tr>
</table>